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AIR MINISTRY

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1. Introduction

It has long been recognised that the visibility from a few hundred feet above ground level in fog may be very different from that observed at ground level. There has been considerable discussion of the possible dangers that this may involve for aircraft trying to land in fog, but much of the discussion has been vague because of our lack of knowledge of visibility at different levels in fog. The plans for observing "slant visibility" that have been in operation for the last few years have produced very meagre results; it is hoped that the new plans now being put into force will be more productive, but the accumulation of data will be a slow process at best. It therefore seems worth while, even on the basis of our present very slender knowledge of slant visibility, attempting to assess how frequently dangerous conditions are likely to arise. The attempt should show what quantities have to be considered in practical problems, and may give some guide to the best method of analysing data obtained in the future. Most important, it can give a factual basis for a decision whether or not to proceed urgently with the development of devices suitable for the routine observation of slant visibility at airfields.

2. Representation of fogs

It has been shown (Stewart, 1957) that in the great majority of cases at Cardington and London Airport there is a simple approximate relation between the slant visibility from a given height in a fog and the horizontal visibility at ground level, the slant visibility decreasing with increasing height. For observations from above the top of the fog, the slant visibility as defined (Stewart, 1957) increases with height and is simply proportional to height above ground, as can be seen by considering that objects at the limit of visibility must always be seen through the same amount of fog.

The variation of slant visibility with height in and above a fog layer is therefore as shown schematically in fig. 1. The line ABC represents a thick shallow fog, DEF a thinner deeper one. Lines BC and EF are simply straight lines from the origin drawn through points B and E, representing slant visibilities at the fog tops. AB and DE are drawn from the equation already derived relating slant and horizontal visibilities.

Each curve is uniquely determined by the point (B or E) representing height of fog top and slant visibility from fog top; these two quantities can therefore be used to specify completely the visibility conditions in a fog, and fogs can conveniently be represented by single points such as B and E on diagrams like fig. 1, rather than by drawing the complete slant visibility curves. It will be seen later that this representation is of some value even when the visibility curve below the fog top does not follow the theoretical model exactly.

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3. Data on fogs at Cardington

Measurements of slant visibility have so far been made on relatively few occasions and they give no reliable information on the frequency of occurrence of different visibility conditions. However, the height of fog top can be estimated fairly accurately from almost all of the numerous temperature and humidity soundings that have been made in fog at Cardington, and in each case the slant visibility from this height can be deduced from the observed horizontal visibility at ground level, as previously shown (Stewart, 1957). We can thus obtain the set of points in fig. 2, representing the visibility conditions in a more or less random selection of fogs at Cardington in the past few years. The points come partly from a series of special ascents made at two- or three-hourly intervals in the fogs of 1951-53 and partly from the routine ascents made at 0730 (since 1956 at 0600), 1200, 1800 and (since 1956) 2400 hr. The times of these routine ascents may tend to exclude newly formed fogs but it is not thought that this possible bias will have any very serious effect on the representativeness of fig. 2 as a sample of all Cardington fogs (the points from frequent soundings throughout the periods of fog do not seem to differ much from the points corresponding to the more widely spaced routine ascents).

The number of points included in fig. 2, in relation to the period and frequency of the observations, is such that each point corresponds to a time of about six hours per year, i.e., the conditions represented by each point may be expected to exist for about six hours in each year.

4. Conditions dangerous to aircraft

Fig. 2 contains the meteorological data required for assessing the frequency of dangerous visibility conditions at Cardington. ("Dangerous conditions" is used here in a restricted sense; the only danger considered is that arising directly from the vertical structure of the fog, other possible dangers such as horizontal patchiness or the glare of a low sun on the fog top being left for separate consideration). Any specification of the visibility conditions that actually constitute a danger can be expressed as an area on fig. 2 and the number of points falling within this area indicates the time per year for which the danger is to be expected. The specification of dangerous conditions is a matter for aviation experts and the tentative specifications put forward here are intended only to provide an illustration of how the meteorological data can be used.

The normal landing procedure in fog is for a pilot to descend to a predetermined "critical height" (which will be taken, for illustration, as 200 ft) and then to decide whether or not to complete his landing. His decision is based on his own impression of visibility conditions from critical height - he would obviously not continue unless he could already see the ground lights or markings well enough to steer by - and on the report he receives of visibility at ground level on the runway. With this procedure it is clear that poor visibility at and above critical height or at ground level does not constitute a danger; dangerous conditions arise only when, with adequate visibility at critical height and on the runway, visibility is markedly worse from some intermediate height. This may happen, according to the scheme of fig. 1, when the fog top is below critical height and when the visibilities have certain values.

For a concrete example we consider landings made at night at London Airport. The approach lighting system has "crossbars" of 10,000 c.p. lights at 500 ft intervals. Simple geometrical calculations show that to be certain of seeing at least one crossbar from about 200 ft the pilot must be able to see the lights at a slant range of 1300 ft. The visibility required to see a light of 10,000 c.p. at this range is 400 ft. The line OA in fig. 3 drawn from the origin through the point representing slant visibility of 400 ft from height 200 ft will therefore separate the representative points of fogs in which the pilot will have adequate visibility at critical height from those with inadequate visibility. Points above the line represent "safe" conditions (because the pilot will realise at critical height that conditions are too bad, and will not continue his approach); points below the line may represent dangerous conditions.

/Below

Below critical height, if we continue to use the criterion of "at least one crossbar visible", the required slant visibility decreases steadily to a value of 130 ft at ground level and we can therefore draw the line AB in fig. 3 with "safe" conditions to the right and "unsafe" to the left. The lower part of this line is unrealistic because close to the ground the pilot ceases to see the approach light crossbars and begins to use the runway lights for guidance; the effects of this change could be shown by appropriate changes in AB, if the lighting and guidance requirements were known.

We are left, therefore, with the narrow area OAB within which points represent dangerous visibility conditions. The area can be still further restricted by bringing in the condition that no attempt at landing will be made unless visibility at ground level (the "runway visual range") is adequate. If we take the limiting condition that 800 ft of runway lighting must be visible and assume lights of 1000 c.p. we find visibility at ground level must exceed 270 ft. With this ground visibility, the slant visibility varies with height as shown by CD in fig. 3. Points to the left of this line represent "safe" conditions - landing will not be attempted - but points to the right may represent unsafe conditions. We are left finally with the shaded area of fig. 3 to represent truly dangerous conditions in which neither the pilot's own observations nor reports from the ground will warn him that if he descends below critical height (and therefore becomes committed to land) he will, for a time, lose the guidance he needs.

The shaded area of fig. 3 has been redrawn on fig. 2 and we can estimate that it contains 1.2 of the representative points, each corresponding to six hours per year. It appears, therefore, that if all our assumptions about fog structure and about visibility requirements are correct, "dangerous conditions" occur at Cardington for about 7 hours per year.

5. Discussion

The estimate of the frequency of dangerous conditions is based on two main assumptions, that the relation between slant visibility and height is given by the theoretical equation in all fogs and that the criteria for adequate visibility are those used in the last section.

The theoretical equation is not applicable to all types of fog, but in practice, at Cardington and London Airport serious departures from it seem relatively rare, with a more or less random sample of fogs. Small random departures from the theoretical relation will not affect the frequency of dangerous conditions greatly; they will tend to remove as many occasions from the danger class as they bring into it. Large departures are rare and will therefore have a small effect on the frequency except when it is extremely small or zero. Our estimate is therefore a lower limit to the frequency of dangerous conditions, but the possibility of freak conditions must be allowed for in addition.

Changes in the criteria for adequate visibility can obviously have a very big effect on our estimate, by changing the position of the lines in fig. 3. As illustrations we may consider the effect of plausible changes of two different types. In the first, we make a numerical change in one of the limiting quantities, the runway visual range limit. If this is varied from the rather low figure of 800 ft to the more usual one of 1500 ft the line CD of fig. 3 is moved so far to the right that the shaded area vanishes altogether. In the second illustration we change the criterion for "adequate guidance" from critical height downwards; instead of supposing that the pilot must be able to see a minimum length of the lighting pattern (500 ft in our previous discussion) we suppose that he must be able to see a minimum angular amount of the lighting pattern, i.e., that the angle subtended at his eye by the length of pattern he can see must remain above some minimum value (which we take to be equal to the angle subtended by 500 ft of lighting when he is at critical height). In fig. 3 this has the effect of turning the line AB until it coincides with AO - and again the shaded area vanishes.

/It

It appears, then, that the greatest uncertainty in our estimate of the frequency of dangerous conditions arises from uncertainty in the criteria for adequate visual guidance. Using what are thought to be fairly realistic criteria we find the frequency to be very low - so low that the chance of making measurements in such conditions in any one year is very small. It also seems likely, with this very low frequency of dangerous conditions, that the dangers arising from horizontal variations in fog density and from time variations are more serious than those due to variations in the vertical, which have been considered here.

6. Conclusions

(a) We cannot decide - even approximately - the frequency of dangerous visibility conditions without a precise statement of what pilots require to see; small changes in requirements produce very big changes in frequency.

(b) Given such a precise statement we can estimate the frequency of dangerous conditions, probably within a factor of two or three, from existing data for SE. England.

(c) A very long programme of measurements will be required to produce any appreciable improvement in the accuracy of this estimate.

(d) Estimates based on present data seem precise enough to permit a decision on the need for the routine operational measurement of slant visibility at airfields.

(e) It seems likely that visibility variations in the horizontal and in time may be a more important source of danger than the vertical variations which have been considered here.

7. Reference

Stewart, K. H. 1957 Meteorological Research Papers, Air Ministry, London, No. 1046.

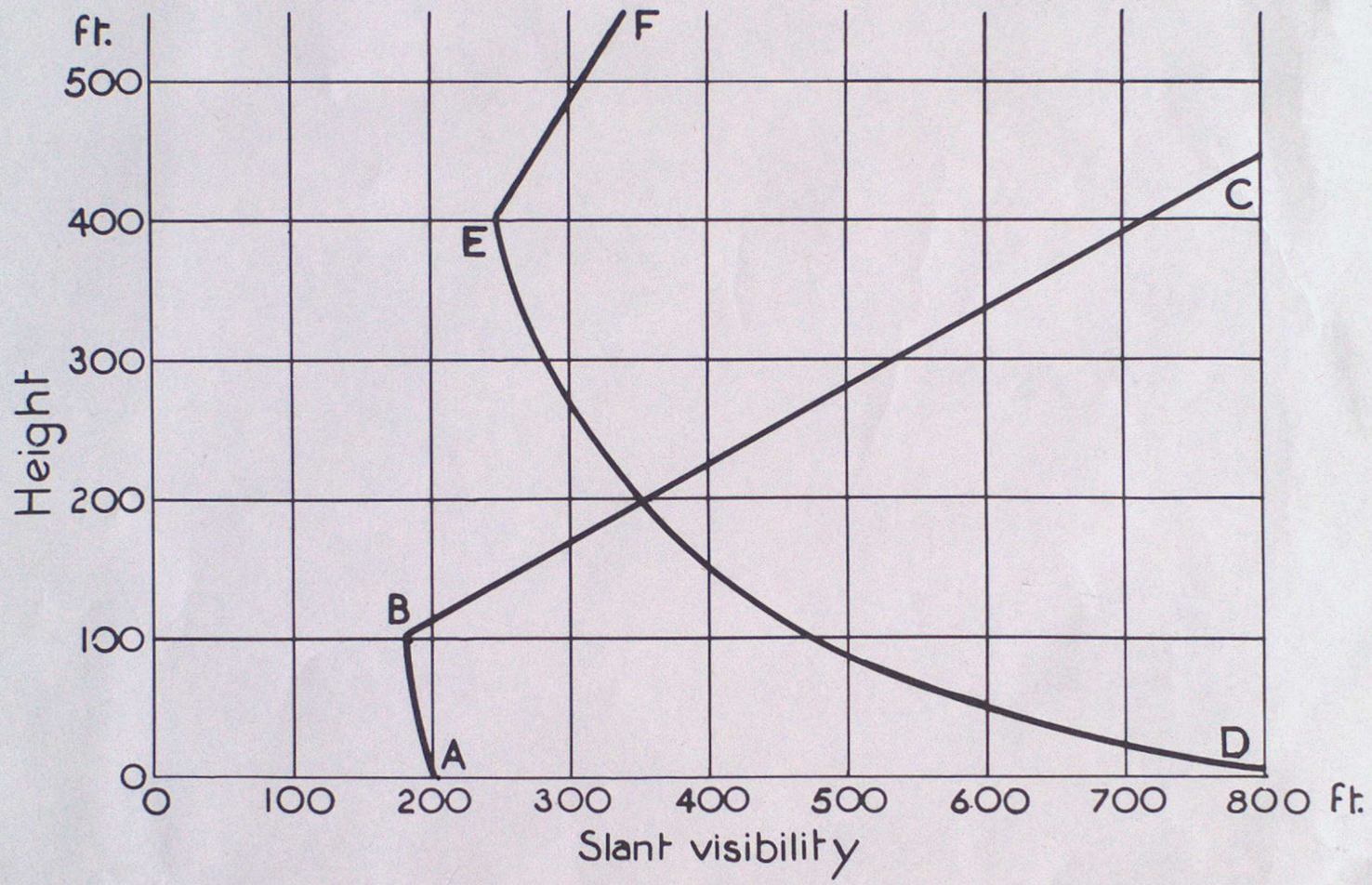

Fig 1. Variation of slant visibility with height in and above two typical fogs.

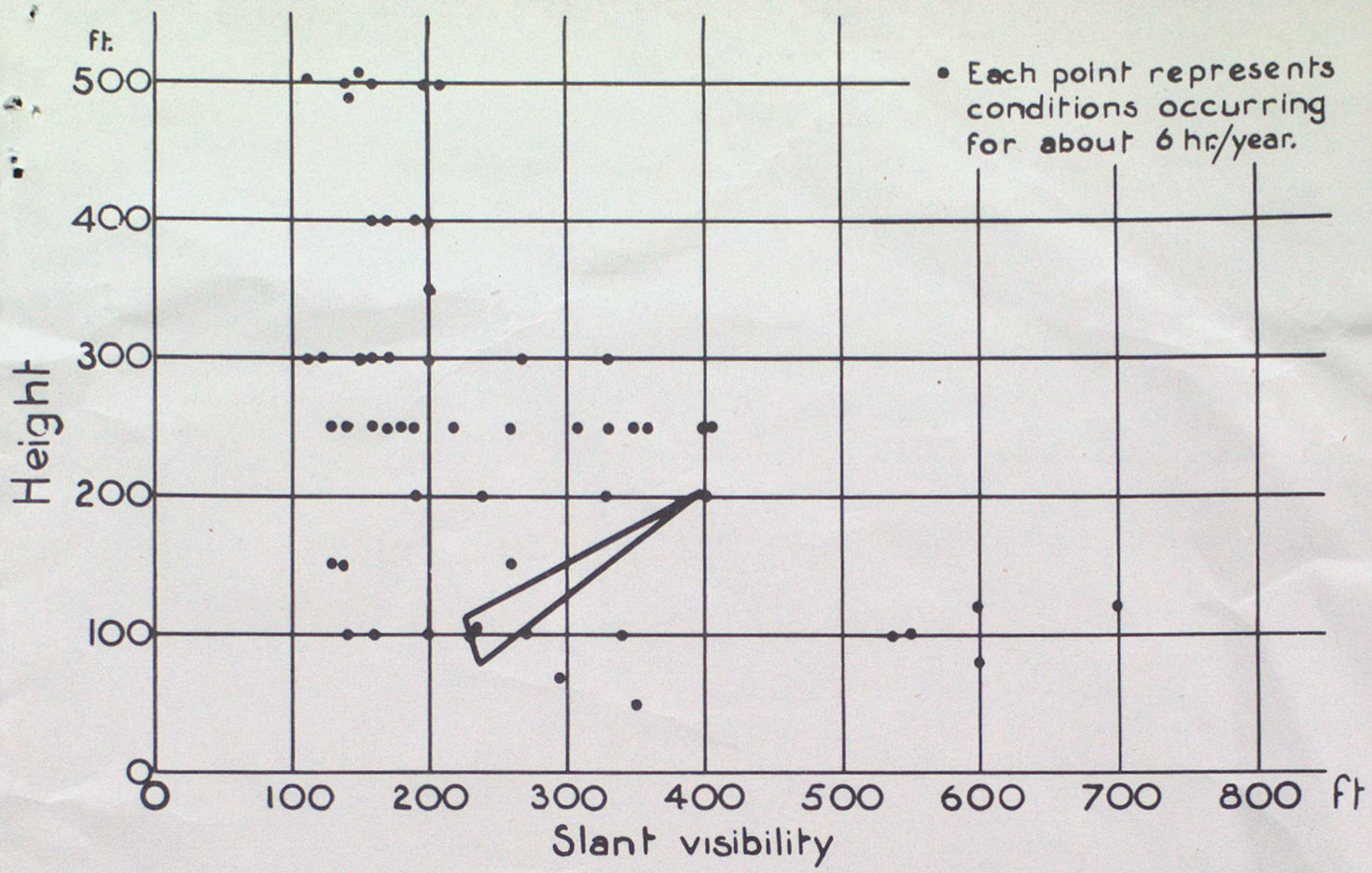

Fig 2. Height of fog top, and slant visibility from fog top at Cardington.

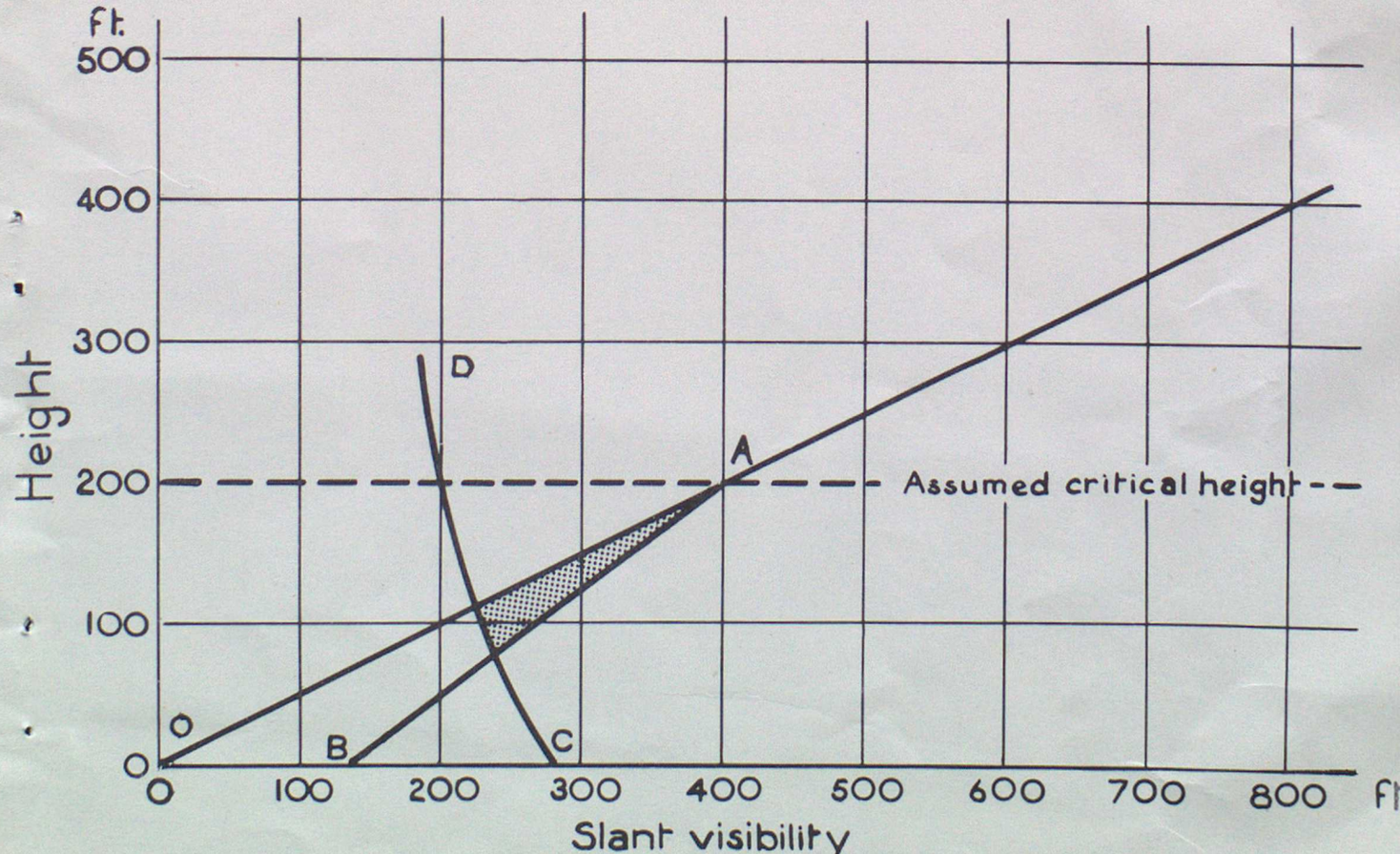

Fig 3. Boundaries of "safe" and "unsafe" areas on slant visibility diagram.